Large-sized Oysters from the Japanese Pleistocene and Their Paleoecological Implications

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INTRODUCTION

Several years ago, Prof. Shoshiro Hanzawa of the Institute of Geology and Paleontology, Tohoku University suggested to the writer the importance of a study on the molluscan fossils from the Pleistocene deposits of Atsumi Peninsula, Aichi Prefecture. By his suggestion a large collection was made and among them, several specimens of unusually large-sized and fairly thick shelled oysters called the writer's attention. From the characteristic features of shell outline, these oysters are easily identified as *Ostrea* (*Crassostrea*) *gigas* Thunberg, a common species in Japan. At the same time it was recognized that their shell outlines are quite identical with the specimens collected by the writer in 1954 from the Pleistocene deposits of Totsuka-machi, Kanagawa Prefecture. Moreover, Araki (1959) recently recorded an occurrence of oysters with similar features from the Pleistocene deposits of Mie Prefecture. *Ostrea gigas* has a wide geographic distribution in Japan ranging from Sakhalin to Formosa, and is also a common species in the late Cenozoic formations in Japan. It is interesting and noticeable, however, that the shells showing the peculiar kind of growth, which have hitherto been seldom found only as living from Akkeshi Bay and Saloma Lake, Hokkaido, occur from the Pleistocene sediments. It should be noted that Nomura (1938) reported on the fossil occurrence of large and thick oysters provisionally identified as *Ostrea gravitesta* Yokoyama based on their heavy shells and large sizes, and stated that they recall the well-kown occurrence of a large and heavy oyster in the present Akkeshi Bay in Hokkaido.

In this article, the writer makes an attempt to explain the paleoecological significance of them through an examination on the fossil specimens and their modes of occurrence, and for the purpose a survey was made of the available data on oyster biology, and a comparison with specimens bearing similar features of growth which are known or have been recorded from other regions or horizons.

ACKNOWLEDGEMENTS

The writer expresses his hearty thanks to Professor Shoshiro Hanzawa of the Institute of Geology and Paleontology, Tohoku University, for his valuable suggestions which stimulated the present work. Particular appreciation is due to Professor Kotora Hatai of the Institute of Geology and Paleontology, Tohoku University, for kindly supervising the present work both in field and in laboratory. Acknowledgements are also due to

Drs. Junichi Iwai and Tamio Kotaka of the Institute of Geology and Paleontology, Tohoku University, and to Dr. Yoshio Araki of the Mie University for their kind information concerning the fossil occurrences of the large oysters in several localities. Thanks are also due to Messrs. Yokichi Takayanagi of the Tohoku University, and to Yu Higuchi of the Kanto Natural Gas Company, for their kind advices on the foraminifers.

MODE OF OCCURRENCE IN EACH LOCALITY

The materials here treated are from only three localities situated on the Pacific side of central Honshu. Precise correlation of the deposits of the three localities is reserved for another opprotunity because the writer's study is still in progress. However, there are features in common between them concerning the mode of occurrence, geological setting, and infered environmental condition, which may have, to some extent, important bearing on the interpretation of the paleoecological significance of the peculiar shaped oysters.

1) Specimens from Kanagawa Prefecture

Locality (Fig. 1) : Cuttings along the Tōkaido National road, extending nearly from north to south through the hilly part of Totsuka-machi, Totsuka-ku, Yokohama City, Kanagawa Prefecture. This area was under construction for a new road when the writer first observed the geology in January, 1954.

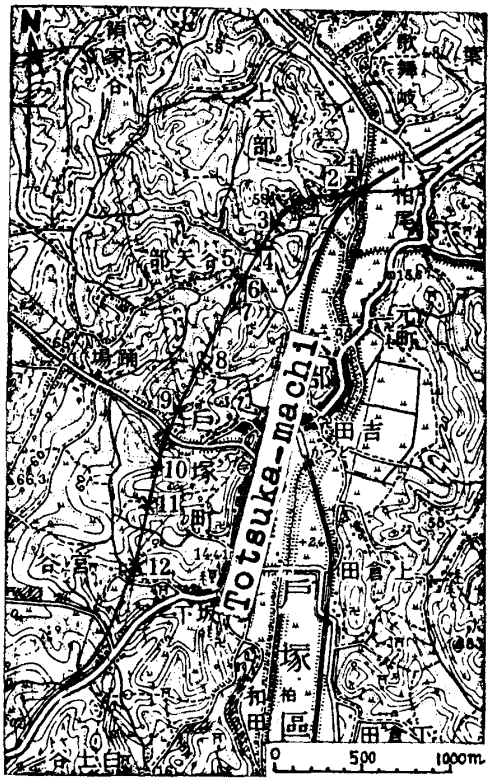

Fig. 1. Map showing the locations of exposures along the new National road through Totsuka-machi, Totsuka-ku, Yokohama City, Kanagawa Prefecture.

Mode of occurrence, geological setting, and depositional condition infered (Text-figs. 2–5) : In the area between points 1 to 7, which is the type locality of the Kuratsubo and Odoriba formations of Otuka (1937), the lower part of the hill consists of grey siltstone (the Kuratsubo) with abundant marine fossil shells, and is overlain by brown, massive fine sands (the Odoriba) partially with contemporaneous erosion surface. At the point 9, about two meters thick mixture of silts and sands intercalating two layers of white tuffaceous clay occurs between the above mentioned sands and silts. At the point 8 and southwards,

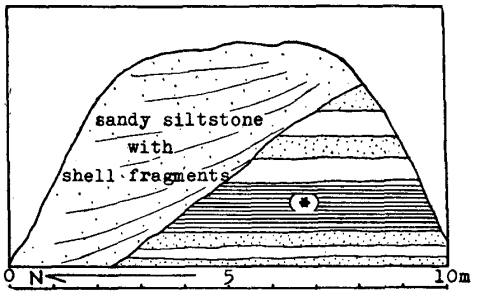

Fig. 2. Sketch of the exposure at the point 10.

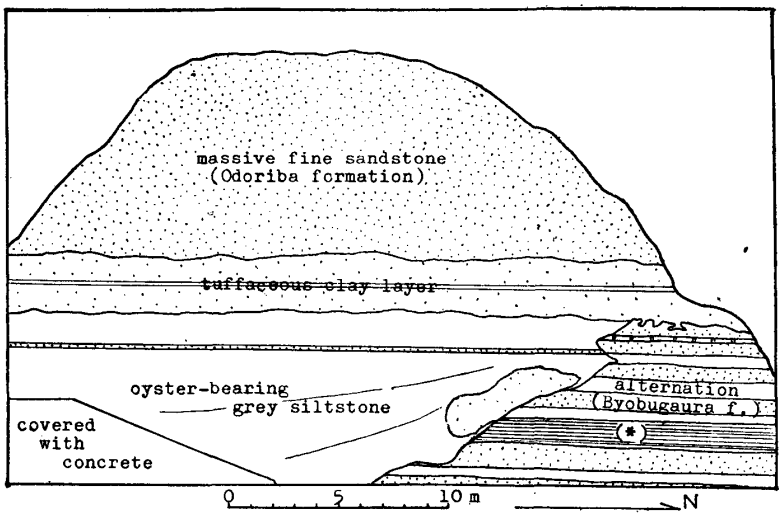

Fig. 3. Sketch of the exposure at the point 11.

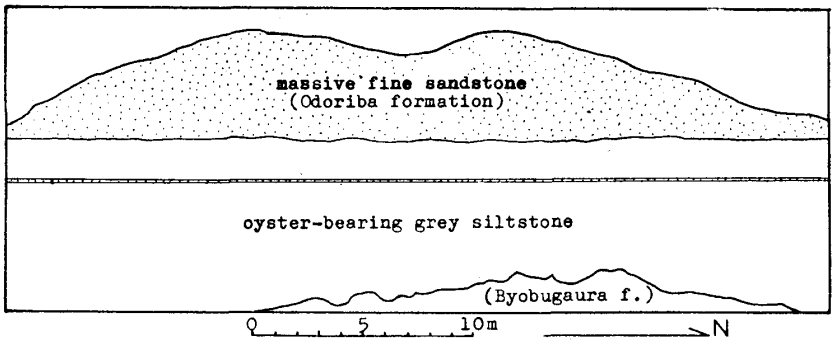

Fig. 4. Sketch of the exposure at the point 12.

an alternation of silts and sands (each bed is 1–2 meters in thickness), a typical facies of the Byobugaura formation (Otuka 1930, 1937) which was observed by Otuka to underlie the Kuratsubo with an unconformity (Otuka 1937), is widely distributed. At the point 8, an about five meters high exposure of an alternation of sands, silts and tuff, which is also of the Byobugaura formation, occupies a rather high (about 32 meters above sea-level) position. At the point 10 (Fig. 2), a sandy siltstone containing fragmental shells abuts against the basement of alternating layers (the Byobugaura) with northwards dipping boundary surface, along which several faint stratifications of the former converge upwards.

At the point 11 (Fig. 3), good outcrops showing quite the same relation as at point 10 are exposed in cliffs opposite each other. The lower alternation is cut by an irregular surface dipping southwards. The depositional features of the upper silts are controlled by the shape of this surface as judged from the arrangement of the fossils and the inclination of faint stratification. A thinly laminated dark grey silt bed in the lower alternation (Fig. 3, (*)) is also recognized as at point 10 and both are considered to be originally a continuous bed. Consequently, it may reasonable to presume that there had been a hillock of basement alternation stretching over the area between the points 10 and 11, and that the upper silts which carry the large oysters to be sediments filled in a rather wide valley cut into the lower alternation.

At this locality the writer collected the following molluscan and foraminiferal fossils.

Table 1

Genus and Species	Fossil-bearing Sediments	
	A*)	B**)
Mollusca:		
Barbatia (Savignyarca) obtusoides (Nyst)		*
Anadara (Tegillarca) cfr. *obessa* Kotaka		*
Anomia cyateum Gray		*
Ostrea (Crassostrea) gigas Thunberg	*	*
Trapezium (Neotrapezium) liratum (Reeve)		*
Cyclina sinensis (Gmelin)		*
Anomalodiscus squamosus (Linnaeus)	*	*
Venerupis (Amygdala) sp.		*
Cerithidea (Cerithdeopsilla) djadjariensis (K. Martin)		*
Batillaria (Batillaria) zonalis (Bruguiére)	*	*
Capulus badius Dunker		*
Foraminifera:		
Astrononion cfr. *stellatum* Cushman and Edwards		*
Elphidium advenum (Cushman)		*
E. clavatum Cushman	*	*
Reussella aculeata Cushman		*
Rotalia cfr. *beccarii* (Linnaeus)	*	*

*) The basal alternation of sands and silts.

**) The grey silts unconformably overlying the alternation (A).

The fossil assemblages both of Mollusca and Foraminifera are of brackish-water strongly suggesting an estuarine or embaymental condition.

The extremely large sized oysters here treated were collected from the above-stated grey silts (B) exposed at the locality 12 (Fig. 4), and their occurrence was not as reef or bank but as large lumps of several shells adhered to one another. Therefore, they may be considered to be transported blocks which had formed an oyster reef in the vicinity of the present locality. Beside them, small sized shells of *Ostrea gigas*, *Cerithidea djadjariensis*, and *Trapezium liratum* are distributed over the surface, together with the specimens of the other rare species. On the contrary, the fossil shells occurring in the alternation (A) are restricted to two horizons of which the lower one contains densely aggregated specimens of *Anomalodiscus squamosus* and *Batillaria zonalis* while the upper is the shell sands composed of numerous fragments only of small sized *O. gigas*.

The foraminiferal assemblages from (A) and (B) are little different from each other in the constituent species. According to Higuchi (1956), who studied the fossil Foraminifera from the area covering the North Miura Penisula, the water temperature indicated by the foraminifers from the Byobugaura formation is much cooler than and in marked contrast to that of the underlying formations. Namely the faunal elements of the Byobugaura formation, comprise such cold current species as *Elphidium clavatum* Cushman and *Buccella frigida* (Cushman). These two species constitute a peculiar foraminiferal fauna as the most predominating two elements in rather shallow water off the coast of Kushiro, Hokkaido*) standing close to Akkeshi Bay where the extremely large sized *Ostrea gigas* is known to

*) According to the oral information from Dr. Y. Takayanagi.

flourish as remarkable oyster-banks. *Elphidium clavatum* is also predominating in the filled-in, oyster-bearing silts (B) at the present locality aside from *Rotalia beccarii* which is known to live in almost any water temperature where brackish water prevails. Further, the Kuratsubo formation, which is exposed at the base of the locality 7 and is regarded as the marine facies contemporaneous with the foregoing oyster-bearing sediments, is also characterized by the predominating occurrence of *Elphidium clavatum* and *Buccella frigidus* over the other eight species, such as *Nonion japonicum* Asano, *Pseudononion japonicum* Asano, *Elphidium advenum* (Cushman),*E. hokkaidoense* Asano, *Rotalia* cfr. *beccarii* (Linnaeus), *R. inflata* (Seguenza), *R. japonica* Hada and *Reussella aculeata* Cushman. These suggest that the water temperature under which the filled-in, oyster bearing sediments (B) were deposited is as cool as that of the Byobugaura formation recognized by Higuchi. Consequently, the latter may be regarded as the forerunner of, and the former as the one formed immediately after the glacial stage represented by an unconformity between them.

Owing to the limited occurrence of the available exposures, there remains slight question concerning the exact relation of the oyster bed to the other sediments in its neighbouring area. Therefore the writer attempts to give only a provisional outline of it in the following lines. According to Otuka (1937), the sequence of the stratigraphic units of the present area is as follows :

Naganuma Series	Odoriba formation
	Kuratsubo formation
	Byobugaura formation
	Taya formation
	Naganuma formation

As already stated above, the Byobugaura, the Kuratsubo and the Odoriba formations are unquestionably recognized in the present series of outcrops. The filled-in, oyster-bearing sediments occupy the horizon between the Byobugaura and the Odoriba with the same relation as observed in the case of the Kuratsbuo formation at the type area. This suggests a contemporaneity between the oyster bearing silts indicating brackish facies and the Kuratsubo formation containing a characteristic marine fauna, being similar, according to Otuka, to that of the present Sagami Bay at the depth of about 30 meters, and the former may have been formed in the valley-like inlet opening to the southern margin of an embayment (the last stage of paleo-Totsuka Bay of Otuka) in which the latter was deposited. According to Otuka, the northern margin of this bay is recognized about 3 kilometers north of Totsuka-machi on the line connecting Maeyamada, Hanezawa, and Okatsu from east to west. From the immediately outside area of this line (Ushiroyamada, Totsuka-ku, Yokohama City), where the Byobugaura is distributed, the similar large oysters have been collected (IGPS*) coll. cat. no. 23774) but their modes of occurrence can not be observed at present because of the covering of the cliff by concrete. However, this may be also explained by the above stated opinion concerning the relation between the brackish

*) Abbreviation for the Institute of Geology and Paleontology, Tohoku University, Sendai.

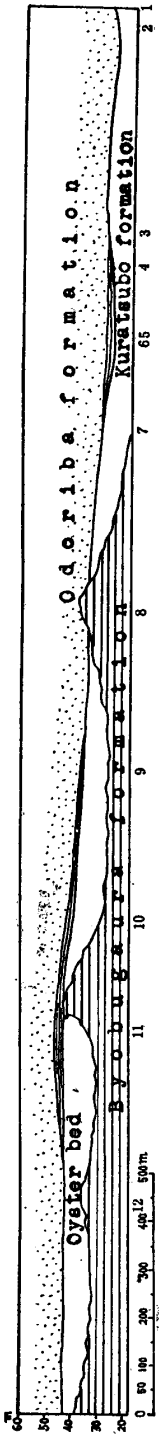

Fig. 5. Schematic profile along the National road with localities indicated by numerals at bottom.

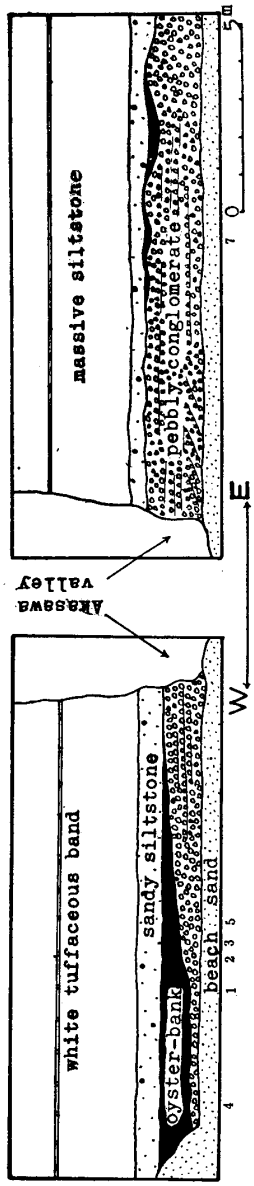

Fig. 6. Sketch showing the occurrence of fossil oyster-bank at the mouth of Akasawa-valley and its neighbourhood, Akasawa, Toyohashi City, Aichi Prefecture. Numerals at bottom idnicate the points where the photographs were taken (Pl. 3˙, figs. 1–5, 7).

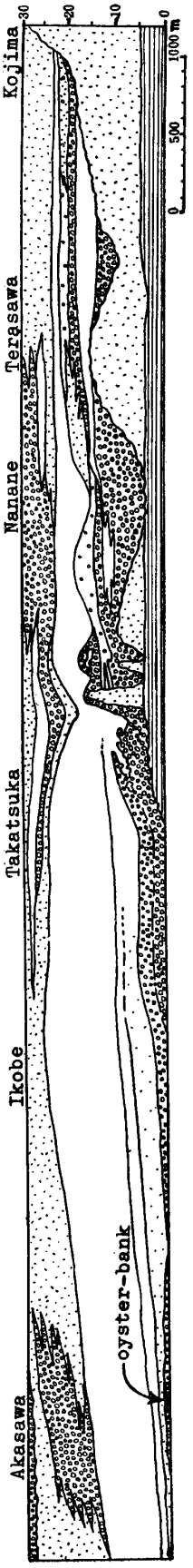

Fig. 7. Reduced profile along the south coast of the central part of the Atsumi Peninsula, Aichi Prefecture.

and the marine sediments. On the other hand, the present oyster-bearing silts is considered to extend its southward distribution as far as Tsutsumigayato and Kurata (about 2.5 km south and about 1.5 km southeast of Totsuka-machi respectively), from where Otuka (1930) reported an occurrence of the large-sized *Ostrea gigas*.

2) Specimens from the Atsumi Peninsula, Aichi Prefecture.

Locality: Basal part of the sea cliff at the mouth of Akasawa valley, Akasawa, Toyohashi City.

Mode of occurrence, geological setting, and depositional condition infered (Figs. 6, 7): A well-rounded pebbly conglomerate, which occupies the lower part of the fossiliferous group comprising the hitherto well-known shell beds (Oinomikado 1933), are exposed at the base of the about 35 meters high sea cliff. Filling the depressions of depositional surface of this conglomerate, some oyster beds, being lenticular in profile, are developed in a distance of about 100 meters. The bed, which is considered to represent an oyster bank, is composed of gigantic shells of oysters which cluster horizontally or in standing position up side down. The arrangement of the shells shows a certain regularity resulting in a flowing appearance when viewed from a distance. Beside oysters, *Trapezium* (*Neotrapezium*) *liratum* (Reeve) and *Corbicula japonica sandaiformis* Yokoyama are often found from the silts filling the narrow spaces between the oyster shells. The oyster beds are overlain by 50–70 centimeters thick bed of sandy silts partly with sporadic granules, which grade into the silts forming the matrix of the underlying oyster beds. This bed rarely contains several molluscs, such as *Corbicula japonica sandaiformis*, *Mactra* sp. *Macoma* sp., *Sanguinolaria* (*Nuttallia*) *olivacea* Jay, and *Ostrea gigas* of small sizes, and is overlain by a thick (about 14 meters in thickness) and massive siltstone containing abundant specimens of *Raeta* (*Raetellops*) *pulchella* (Adams and Reeve) together with rarely occurring specimens of *Dinocardium braunsi* (Tokunaga), *Dosinia* (*Phacosoma*) *troscheli* Lischke, *Mya* (*Arenomya*) *japonica* Jay, *Periploma* sp., *Umbonium* sp., *Natica* (*Tectonatica*) *janthostomoides* Kuroda and Habe, and *Rapana* aff. *bezoar* (Linnaeus).

The relations between these beds are all conformable. As the strata exposed in the sea cliff along the southern coast of this peninsula are gently dipping towards the west with a few degrees, the thickness of the conglomerate partially covered by the oyster beds gradually increases towards the east, and near Takatsuka a part of another group appears under the conglomerate exposing the whole thickness (about five meters) with an erosion surface between. As shown in the Fig. 7, the underlying group which is the lowest one as far as the writer could observe through the study on the surface geology of Atsumi Peninsula, is composed of a sandy siltstone with fine lamellar structures below and of massive fine sands above. The former exhibits contortions having a great variety of structures (Hayasaka and Iwai, 1959) and seldom yields marine shells, and the latter, which is barren of fossils, rarely contains very thin layers of small granules intermittently. These two lithofacies are conformable with each other and irregularly cut by an erosion surface with strong relief ranging from zero to 30 meters in height above the sea level, and are considered to had been a land or submarine bank when the overlying fossiliferous group was deposited. Consequently, the conglomerate underlying the oyster beds is regarded as the basal con-

glomerate of the fossiliferous upper group, which shows a complicated lithofacies near the base and abuts against the surface of the basal group inclined westwards as a whole.

From the above stated features, the oyster-bearing sediments are infered to had been formed in an embayment surrounded by a land composed of the basement rocks at the beginning of transgression immediately after the glacial stage which is provisionally convinced by the writer based on the occurrence of an unconformity with the underlying basal group. As already mentioned, the deposition of them is followed by that of the purely marine silts and sands containing rich molluscan fossils most of which represent common living species in this region. It is noticeable, however, that the marine fauna does not include the specimens of *O. gigas* which flourished at the early stage of transgression but contains numerous specimens of *Ostrea* (*Crassostrea*) *pes-tigris* Hanley and *Ostrea* (*Ostrea*) *densellamelosa* Lischke. This suggests an existence of environmental change not only from brackish to marine but also climatic probably from cool to temperate.

3) The specimens known from the Pleistocene deposits of Mie Prefecture, has been described by Araki (1959) with a detailed note on the mode of occurrence and geological setting, and he tentatively considered "that the faunal association from its peculiarity (coexistence with *Trapezium liratum*) may represent a sedimentary environment cooler than that of the seas bordering the present day Mie Prefecture." Here the writer will only quote from Araki the exact locality and geological formation of the oyster-bearing sediments.

Localities and geological formation: Under the vegetable garden in the west of Mitachi Temple, Mitachi, western part of Yokkaichi City (Mitachi formation); small cliff in the paddy-field along the Ai River in the northeastern part of Konobe, Hisai-chô, Isshi-gun (Konobe formation): under the Terrace deposits exposed near the road leading from Handa to Hisai-chô, middle part of Handa, Tsu City (Konobe formation).

REMARKS ON THE SPECIMENS HERE TREATED

The outlines of the shells are fairly variable but are generally of elongated wedge-shape. Only seldom are wider, oval-outlined valves found from such incompletely developed oyster banks which are rather thin and not so crowded with the oyster shells. The valves being foliaceous are fragile chiefly because of the extremely chalky texture of the calcareous shell layers. The left valve, which is convex and partially provided with rather faint radial plications on the surface of its younger lamellae, is longer than the right being almost flat and having no plications. Both valves are tapering at the beaks. Ligamental furrow of the left valve in which fits a median ridge of the right valve is considerably deep and limited by narrow ridges on both sides. Both sides of the hinge line are simple and without any dentition. In both valves, numerous, rather thin lamellae are imbricated at low angles with the ligamental furrow or ridge, though in the cross section they tend to fuse with each other and form rather thick and massive chalky layers. There are several extremely compressed specimens, of which left valves are much more convex than the right and are extremely thickened at both anterior and posterior sides in comparison with the central part where the muscle scar is impressed. Dimensions of the selected specimens are given in the following table. The foregoing morphological characters

Table 2

Specimen			Height	Length	Thickness		Height of ligamental furrow or ridge	Height and breadth of muscular impression	
Locality	No.	Valve			At the center of basal line of cardinal area	At the center of muscular impression			
Totsuka-machi	1	right	35.5	13	3.8	1.3	6.8	4.2	3.8
		left	37.7	14.5	3.4	1.9	about 10.5	4.7	3.8
Ushiro-yamada, Totsuka-ku	2	right	31	11.5	4.1	0.6	8	8	5
		left	about 37	about 14	2.1		10.5		
Atsumi Peninsula	3	right	35	11					
		left	37	13					
	4	right	34	14					
		left	35	15					

Specimen no. 1: Illustrated specimen in the Plate 38.
Specimen no. 2: IGPS coll. cat. no. 23774

of the present specimens correspond quite well with that of the specimens described and illustrated by Hirase (1930) under the name of *O. gigas* Thunberg apart from *O. laperousii* Schrenck, except for the development of the extremely chalky shell texture giving the appearence of heavy and stout shell.

REMARKS ON THE SPECIES *OSTREA* (*CRASSOSTREA*) *GIGAS* THUNBERG

As is generally known, oysters are liable to change their morphological features under the influence of environment. *O. gigas* is no exception to this rule, and has been known to represent several different types of shells in different places. It seems to be necessary for the present purpose to know the actual states and causes of their distribution through the survey on extensive literatures on the living *O. gigas*, on which a brief note will be given in the following lines.

Ostrea gigas was originally described by Thunberg in 1793 based on the Recent specimens from Japan. Beside several morphologic features, he emphasized that the shells are quite variable in size and weight, but they often exceed any other hitherto known species in size, thickness, and weight.*) Long after him, Schrenck (1867) and Crosse (1862) described *O. laperousii* and *O. talienwhanensis* respectively, regardless of each other and of Thunberg's species. Schrenck's *laperousii* is also fairly variable in size and thickness but comprises exceedingly elongate and thick specimens as seen in the northeast American oyster "*O.virginiana* Lest." (= *O. virginica* Gmelin) with which he compared the new species, while Crosse's *talienwhanensis* is based on the specimens having large and heavy shells. In 1869, both of them were correctly regarded by Lischke as synonyms of *O. gigas* Thunberg. As stated above, every author recognized the characteristic occurrence of

*) According to the Schrenck's citation.

extremely elongated and fairly thick shelled specimens among the present species, but no one separates them as a different species from the rather thin, broad and medium sized specimens.

In Japan, *O. gigas* is a representative species which has been cultivated for a number of years. Among the species, two different types of shell outline are recognized, and each of them has hitherto been called under different names, that is, Nagagaki (the elongate oyster) or Ezogaki (the Hokkaido oyster), and Magaki (the true oyster) or Kaki (the oyster). Further, it has been generally known that Nagagaki (or Ezogaki) is restricted in distribution to the northern part of the Japanese Islands (Northeast Honshu and Hokkaido), and that the extremely grown-up specimens of Nagagaki having extraordinarily elongated and moderately thick shells occur in such particular localities as Akkeshi Bay and Saloma Lake in Hokkaido (Hirase 1930, Nomura 1938, Kira 1959). In 1930, Hirase who published a monographic work on the Japanese oysters considered that three different species are contained among the specimens hitherto regarded as *O. gigas*, and gave the name *gigas* to the shells of elongate type and *laperousii* and *rivularis* Gould to the others. Setting aside the species *rivularis*, the specific discrimination between *gigas* and *laperousii* corresponds to that held by the Japanese names (Nagagaki and Magaki). On the other hand, Wakiya (1910, 1929) claimed that Nagagaki merely represents the full-grown specimens of Magaki, and as the cause of the restricted distribution of Nagagaki he pointed out that the younger ones are more delicious in flavour than the older and they are gathered and used for food at the age of about two when their length is no more than 120 mm (Wakiya 1929) and this custom more prevails in the southwestern part of the Japanese Islands than in the northeastern part where marine products are more abundant than the former. As an endorsement of this opinion, he further stated that Nagagaki is found not only in the northeastern part of the Japanese Islands but also in Ryukyu Islands and Korea where the demand for oysters as food is rather slight (Wakiya 1910). The difference in shell outline upon which the specific discrimination was made by Hirase is nowadays generally recognized as merely a difference in life form represented in mode of growth (Kuroda and Habe 1952, Habe 1951). However, it is noticeable, as a phenomenon controlled by some natural environmental factors independently of the artificial factor recognized by Wakiya on the average sized shells of Nagagaki, that the extraordinarily large sized shells, which closely resemble the Pleistocene specimens treated here, seem to be restricted in distribution to several embayments at rather high latitude, such as Akkeshi Bay and Saloma Lake in Hokaido already stated above, Talien Bay, Liaotung Peninsula in China (Crosse 1862), and the bays along the Japan Sea coast of Sakhalin and Primorskaya (Maritime Province) in U.S.S.R. (Schrenck 1861). Hirase (1930) convinced that those extremely large type (typical *O. gigas* of him) may had been rather widely distributed in Japan, and as an endorsement of his opinion by fossil specimens he cited a private message from Prof. G. Toba who has observed a fossil occurrence of it regardless of its geological setting in Iwate Prefecture, Northeast Honshu.

Under these circumstances, it is interesting to know that the gigantic specimens of *O. gigas* rather commonly occur in the Pleistocene deposits of Central Japan situated far

south of the area where they occur at present, and they seem to suggest changing environmental condition with the lapse of time.

PALEOECOLOGICAL CONSIDERATIONS

One of the common features between the gigantic specimens of both living and fossil oyster is that they closely cluster and form a remarkable oyster bank (Kinoshita 1935, Johnson and Foster 1951, Sassa 1957). As observed at Totsuka-machi, Kanagawa Prefecture, the small specimens having rather round outline are scattered without forming a bank in the muddy sediments contemporaneous with the large oysters which are considered to had formed an oyster bank. According to Wakiya (1929), the shell size and outline of this species are correlative with environment as well as with age. He recognized that the specimens living on a soft bottom have a much more elongated shell than those living on a harder bottom, and that the shell is much longer when it occurs in a cluster than in those occurring separately. The latter has also been recognized by Ryder (1884) on the "abnormally elongated" specimens of *Ostrea virginica* Gmelin, which is a common east American oyster ranging from Prince Edward Island to the West Indies, and is generally known to represent in the northern part of its range an extremely elongated growth in crowded banks (Ryder 1884, Reeve 1873, Smith 1951). Ryder gave an explanation as follows. "This elongation of the valves is due to crowding, and also to the sedimentation or silting of sand or earth between such individuals as grow closely together on the bottom. In the struggle for existence the animal is impelled to grow upwards from these causes in order to reach its food and the water necessary for respiration. Consequently the shelly deposit is laid down by the mantle mainly at the free ends of the upwardly directed valves, so that the latter grow only in length and not in width, thus giving rise to the extremely elongated type often met with." Through the detailed observation in the field, it was recognized that the elongated feature of shell outline is a definite character but the shapes of both lateral margins are fairly variable, and the neighbouring margins of two different specimens are controlling in shape each other to form a counterpart. Judging from the above stated several features, the peculiar kind of elongation may be not resulted from a peculiarity of some physiologic control but rather from the physical restriction of growth space caused by the bank-building.

Next, it is remarkable that though the present species is a brackish water oyster generally prefering the inter-tidal zone near the low tide mark, the occurrences of extremely large and thick specimens both of living and fossil seem to be restricted to rather small, partly closed inlets or bays protected from stormy waves or currents. This is considered to be a favourable condition to form oyster banks because the oyster shells are not transported after death to other places and play an important role as the substratum to which new oyster larvae attach. Further, such kind of embayments is generally abundant in food (nutrients) and lacking in many oyster enemies such as drills, starfish, and the boring sponge which are living in more saline water (Korringa 1952). On the other hand, however, water salinity of such environment is apt to be seasonally dropped by the influence of rivers flowing into the bay, and the lowering of water salinity may arrest the

development of the present species especially in the early developmental stage. This unfavourable environmental factor may not satisfy fundamentally the reef-building condition in spite of several other favourable ones as stated above.

An experimental result on the influences of water temperature and salinity upon the species *Ostrea gigas* in its early developmental stage has been given by Amemiya (1928). According to him, "at a low termperature, the range of salinity which is available for the development of the oyster is wider than that at high temperature and especially in the lower part of the range the development becomes rather more favourable." Further he stated as follows. "In the northern part of Japan, in Hokkaido or Saghalin, we often observe that the oyster, such as *O. gigas* live in water of very low salinity, in lagoons, estuaries and near river-mouths. Possibly the cold temperature of that region may have some influence upon the development of the oyster, and this experimental result of mine seems to be suggestive." By this special character of *O. gigas* recognized by Amemiya, the unfavourable lowering of water salinity stated above may be conquered by the oysters in rather high latitude region such as Hokkaido and its north. On the contrary, in the lower latitude region, the development of the oysters may be arrested by the low salinity even if the other environmental conditions are satisfied.

The above stated relation assumed from the experiments on the living *Ostrea gigas* corresponds quite well with and seems to explain the actual distribution of the gigantic specimens restricted to Hokkaido and northwards. As stated in the foregoing section, the geological data on each locality from where the gigantic oysters were collected indicate rather cool condition remaining immediately after the glacial stage and it is also consistent with the above stated ecological feature of *Ostrea gigas*.

The moderately thick shells of the present specimens which are considered as a result of their unusual longevity may probably be caused by several particularly favourable conditions such as sheltered, teeming with food, and being in rather weak suffering from enemies and from deposition of silts which is regarded as an important factor especially in winter mortality (Korringa 1952).

As a conclusion, it may be reasonably said that the extremely elongated and moderately thick-shelled specimens of *O. gigas* are a product of such a particular environment as partly closed brackish water embayment protected from stormy waves and currents to permit oyster reef-building, and besides, situating at rather high latitude or under the influence of low temperature.

In addition to the foregoing considerations, several hitherto known fossil occurrences of the present species and its alliance from the older formations will be mentioned in the following lines. As stated in the foregoing section, *O. gigas* has been known to occur rather commonly in the Cenozoic formations of Japan, especially of Miocene and later (Nomura and Hatai 1937, Otuka 1938), and some of them have been found to be in remarkable reef form. The existence of thick (0.5–3 m) oyster-reefs in the lower part of the Odaira (Kitamura et al. 1956, Kitamura 1959) and the Motohata (Hayakawa et al. 1954, Kitamura 1959) formations, correlatives of the Pliocene Tatsunokuchi formation in the Sendai City area, has been reported. These two formations are developed in the northern

part of the Kitakami River Valley area where the Pliocene formations are widely distributed under the form of an embayment opening to the south. The oyster reefs, occupying the marginal portion of the bay head area, exist in the sediments deposited at the beginning of marine transgression. Those are overlain by thick sediments containing abundant marine molluscs, although the reefs themselves are built of oyster shells and seldom yield the shells of *Trapezium* and *Batillaria*. The oyster attains a length sometimes of nearly 30 centimeters but the thickness and breadth are somewhat less than that of the Pleistocene specimens. This may mean rather short span of their life resulted probably from the rapid sedimentation then prevailing (Kitamura 1959). Though the further details must be expected in the future study, it is interesting and noticeable in connection with the foregoing ecological feature of the present species, that the Tatsunokuchi and its correlative formations have been regarded as the sediments deposited under cool water condition mainly based on the characteristic features of its molluscan fauna (Nomura 1938, Hayasaka 1956, Kotaka 1958).

A well-known large sized oyster from the Japanese Miocene is *Ostrea gravitesta* Yokoyama (1926), which is closely allied to *O. gigas* (Kuroda 1937) and is hardly discriminated from the latter species aside from its large size (240×140 mm), great thickness (50 mm) of the shell and extreme convexity of the right valve (90 mm in depth). Occurrence of this species is restricted to the shallow water facies of the early Miocene formations with the warm water fauna characterized by tropical genera (Kotaka 1958). The specimens are always found to occur not as banks but separately. Through the close examination on the specimens at hand, the following two points were easily recognized. First the shells are rather oval in outline than elongated as seen in the elongate type of *O. gigas*. This seems to be consistent with the fact that they occur separately. Second, the shell layer bounded by two growth lines is much thicker than that of *O. gigas*. This may be a cause of the extremely thick and the convex shell features and suggests that they were secreted, under the favourable high temperature condition (Korringa 1952), and thus are provided with much more shell material than *O. gigas* showing thin lamellar structure.

It is interesting to know that the large oysters of Pliocene and later and of early Miocene are recognized to form a marked contrast to each other with regard to their ecological implications. *O. gravitesta* is a representative form resulted from the high temperature prevailing in the Japanese Islands during the early Miocene time, while *O. gigas*, which seems to had flourished as the climate became cool in the later time, is considered to be a rather cool water form often forming remarkable banks in some protected embayments under low temperature. The latter species might attain the maximum range of geographic distribution in a certain stage of the Pleistocene epoch when the banks of this oyster seem to had fringed the greater part of the Japanese Islands.

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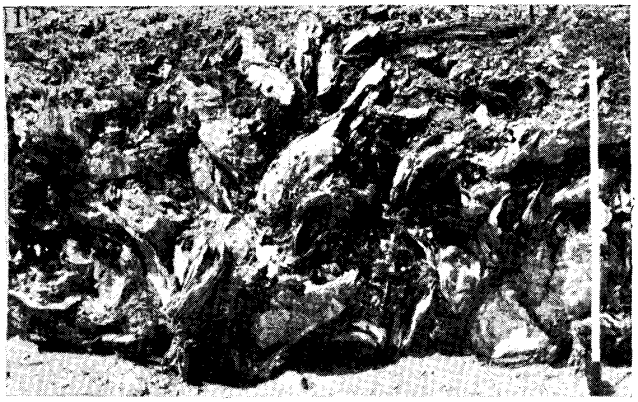
EXPLANATION OE PLATE 37

Fossil oyster-banks in the Atsumi Peninsula, Aichi Prefecture

Figs. 1–5. Oyster-bank developed on the west side of the Akasawa valley (Text-fig. 6). Total length of the scale in Figs. 1 and 2 is 50 centimeters.
Fig. 6. Different outlines of some specimens.
Fig. 7. A poorly developed oyster-bank exposed on the east side of the Akasawa valley (Text-fig. 6).

EXPLANATION OF PLATE 38

Figs. 1a, b, 2. Wedge shaped specimens of the large-sized oyster, *Ostrea* (*Crassostrea*) *gigas* Thunberg. 1a ; inner side of the left valve, of which dorsal and ventral parts are somewhat fractured. 1b ; outer side of the left valve. 2 ; outer side of the right valve.
Fig. 3. *Cerithidea* (*Cerithideopsilla*) *djadjariensis* (K. Martin) ×1
Fig. 4. *Trapezium* (*Neotrapezium*) *liratum* (Reeve) ×1
All of the illustrated specimens are from Totsuka-machi, Kanagawa Prefecture.


1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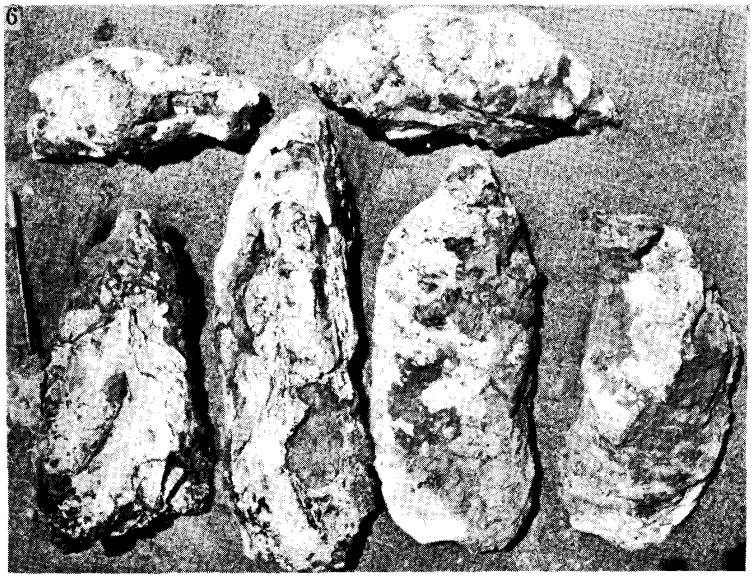
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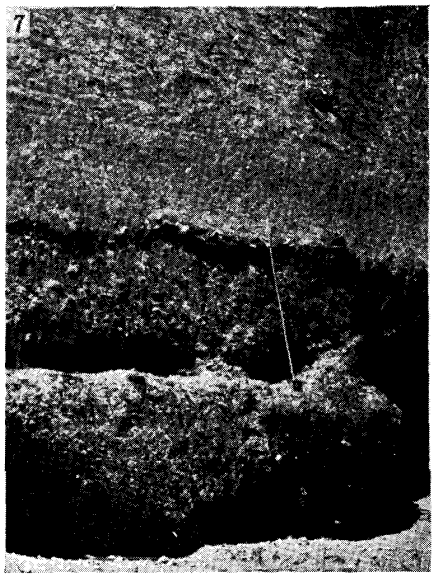
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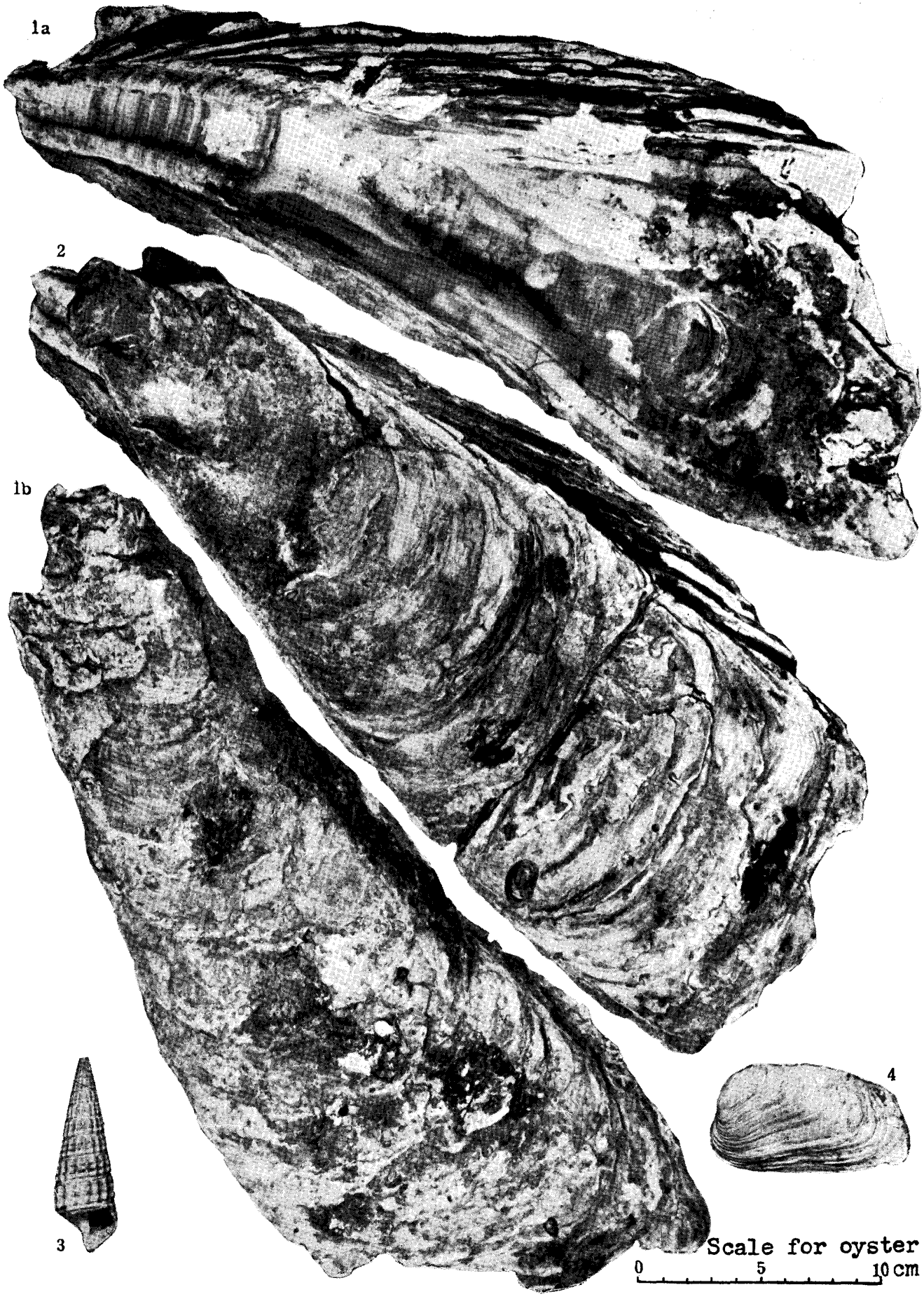
1a
2
1b
3
4
Scale for oyster
0 5 10 cm